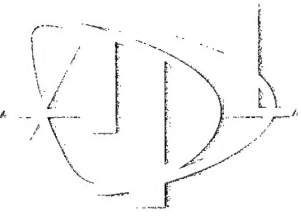
Report of a Survey of US Academic Programs in Ocean and Underwater Acoustics

by K.W. Lackie

Technical Report
APL-UW TR 9704
December 1997



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ONR Grant N00014-96-1-0246

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"No country has a moral right to demand that her soldiers and sailors go into battle with strength and equipment inferior to those of her opponents."

— Representative Carl Vinson, sponsor of H.R. 5911 (79th Congress), which established the Office of Naval Research

ABSTRACT

Underwater acoustics remains the principal means to detect and locate submarines and other underwater objects. For this reason, the Office of Naval Research has sponsored a vigorous research program in underwater acoustics and related fields at both academic institutions and Navy in-house organizations for many years. Unfortunately, no other Federal Government funding agency sponsors research in this area, and as a result the health, strength, and growth of the field in the US depends entirely on the ONR program. Interviews of senior US acousticians and visits to a number of major institutions indicate that recent reductions in Naval research budgets have caused a significant decline in the vitality of the ocean acoustics research community in the US, especially in its capability to train graduate students in at-sea experimental techniques and maintain its sea-going infrastructure. Although a number of initiatives are identified that would improve the situation, only an increase in financial support will completely solve the problem. The current level of Federal funding is inadequate to support long-term Navy requirements for acousticians, though it may be adequate for the current environment of reduced budgets and priorities. The strength of this field, virtually the only one entrusted entirely to ONR's care, is not being sustained.

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EXECUTIVE SUMMARY

Despite the many changes in the world threat environment, the one component of US strategic deterrence that remains relatively invulnerable to hostile attack is the US nuclear submarine fleet. Significant investments in unconventional systems have not changed the fact that underwater acoustics is still the principal means of detecting and locating submarines and other underwater targets. A 1986 study[1] by the Naval Studies Board (NSB)* noted that the Office of Naval Research (ONR) is the only sponsor of research in ocean acoustics and thus "is almost single-handedly responsible for the health, strength, and growth of this important discipline." Another NSB study[2] noted that the research base in the physics of acoustics was small and depended to a significant degree on support from ONR. Both studies called upon ONR to assume national responsibility for maintaining not only the health of the research base in these areas but the supply of acousticians who would support the Navy's future R&D requirements.

Recent DOD budget cuts have forced further reductions in the Department of the Navy's research budget and comparable reductions in the level of funding invested by ONR in acoustics research. ONR has become concerned that this level of investment may no longer be sufficient to maintain the future of this important, Navy-unique discipline.

As a result, ONR asked the Applied Physics Laboratory at the University of Washington (APL-UW) to assess the probable health of ocean acoustics science and technology in the 21st century. This was done by examining the current and future supply of ocean acousticians through interviews of senior US acousticians and visits to a number of major acoustics institutions. The specific goals were to

- Determine if the pipeline of young ocean acousticians is robust enough to support long-term Navy needs.
- Determine if the shrinking market is creating an imbalance among the various components of the Navy's ocean acoustics community.
- Determine if the current situation is likely to provide a continuing supply of up-and-coming superstars.
- Address other items and issues as they arose.

The more important conclusions of this study are listed below.

- ONR remains the only sponsor of ocean acoustics research in the US, and its investments in this field have a direct and immediate impact on both the health of the research and the number of graduate students. The recent budget reductions have caused a significant decline in the vitality of the ocean acoustics research

*A list of acronyms and abbreviation used in this report and their definitions is given in Appendix E.

community in the US. Although the study identified a number of ways to improve the situation, only an increase of financial support will completely solve the problem. The current level of Federal support is inadequate to support long-term Navy requirements for acousticians, though it may be adequate for the current environment of reduced priorities and budgets.

- Recent advances in technology and our understanding of the ocean offer the promise of real breakthroughs in underwater acoustics and acoustic ASW capabilities.
- Most of the major oceanographic institutions are struggling to maintain their capability to do experiments at sea and are in danger of losing their infrastructure of sea-going support personnel and specialized equipment.
- As a possible result of this situation, recent and current graduate students in acoustics are not getting as much at-sea field experience as those of a decade ago; many are more theoreticians than ocean acousticians.
- Research staffs at US institutions with programs in ocean acoustics are aging owing to a lack of support for recruiting.
- The number of graduate students in acoustics is declining at most academic institutions, and the number of US nationals studying in the field is dropping even more quickly. While much of the decline is due to the reductions in research funding, it also reflects the lack of job opportunities in the field.
- Researchers in most other areas of science can go to other sponsors for funding if their ONR programs get cut. Researchers in acoustics have no other alternatives.
- The area of physical acoustics and the physics of acoustics seems to be in less jeopardy than that of ocean acoustics. First, the growing demand for physical acousticians in other areas (e.g., vibration and noise control) seems to be maintaining the vitality of that part of the field; second, *some* of the Navy's requirements for researchers in the area of structural and physical acoustics can be filled by those with other skills (signal processors, electronic engineers, etc.).
- The Navy laboratories/centers seem to be shrinking at about the same rate as the academic institutions and are in danger of losing essential corporate memory.
- The size of the average research grant has declined to the point that principal investigators are spending more time preparing proposals (and less time advising students) than ever before. This has the effect of keeping everyone alive and no one happy.

- Canceled programs and mid-year program cuts are extremely disruptive and destroy attempts to improve collaboration and joint programs.

Suggestions of some possible ways to improve the situation are listed below.

- Take actions (not necessarily limited to those listed here) to maintain the production of students receiving graduate education in acoustics, even if many of those receiving such education do not take jobs in Navy R&D.
- Take public action to recognize the importance of ocean acoustics to the Navy by increasing funding, protecting the program from cuts, establishing research chairs and student awards, or other appropriate, high-visibility actions.
- Discuss the lack of support for ocean acoustics research with the directors of such agencies as the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and the Department of Energy (DOE). These agencies have traditionally relied on ONR to provide the people and tools needed for other acoustics applications.
- Establish an ocean acoustics infrastructure fund to reduce the cost of doing ocean acoustics field work and manage at least some of the equipment purchased with these funds as national assets available to all users.
- Establish an Ocean Acoustics Scientific Advisory Panel to engage the community in the process of formulating and overseeing the ocean acoustics research program.
- Make a serious effort to increase the average grant size and commit to more multiyear projects.
- Integrate 6.1 and some 6.2 program management responsibilities in ocean acoustics and encourage joint academia-Navy laboratory/center 6.1 and 6.2 proposals in some areas.
- Engage other Navy offices in discussions to improve the integration of ONR-sponsored science and technology work with higher-level R&D programs that have major ocean acoustics components.
- Designate a limited number of academic institutions as Institutes of Naval Ocean Acoustics to serve as central sites through which ocean acoustics research would be administered.
- Establish a counterpart to the "ARL Project" focused entirely on ocean acoustics.
- Establish fellowship programs focused entirely on ocean acoustics.

- Establish an ocean acoustics summer internship program for undergraduates between their junior and senior years.
- Use topical workshops to improve synergy between the Navy laboratories/centers and academia, to develop joint laboratory/academia research programs, and to better connect research with requirements.
- Use the foregoing mechanisms to increase the involvement of the community in planning broad, long-range programs and then execute these plans wherever possible.

1. BACKGROUND

The US Navy has long depended on science and technology to improve the effectiveness of its war-fighting systems. The development and testing of armaments and materials for the Navy began in the mid-1800s; however, defense-related research and development as it is understood today did not begin until shortly after World War I. In 1915, in an interview in *The New York Times*,[3] Thomas Edison had suggested

> "I believe that...the Government should maintain a great research laboratory jointly under military and naval and civilian control. In this could be developed the continually increasing possibilities of great guns, the minutiae of new explosives, all the techniques of military and naval progression without any vast expense."

Although action on the suggestion was delayed by World War I and a dispute over where the laboratory should be located, the Naval Research Laboratory (NRL) was finally established in 1923 as the first government-owned research establishment. Reflecting the enormous importance the Navy placed on both communications and undersea operations, even at that early date (radar had not yet been invented, and sonar was in its infancy), the first two divisions established at NRL were Radio and Sound.

Despite this progress, US investments in defense-related R&D were very modest, and as the threat of a new world war grew in the late 1930s, it became obvious that many of the nation's war-fighting technologies were obsolescent at best. (In a recent speech, Norman R. Augustine, chairman and chief executive officer of the Lockheed Martin Corporation, noted that the US has been unprepared for six of the last seven wars in which it has been engaged, Desert Storm being the exception.[4] Reference 5 gives a pre-WW II view of US preparedness. Appendix A lists several examples of US WW II war-fighting systems that were inferior to those fielded by other nations.) As a result, a major government initiative was launched to apply the skills and knowledge of the academic community to improving the effectiveness of American implements of war. In 1940, President Roosevelt established the National Defense Research Committee (NDRC) and appointed Dr. Vannevar Bush, then Vice President of the Massachusetts Institute of Technology (MIT), as its chairman. NDRC was not intended to replace the R&D work ongoing at laboratories like NRL, but rather to supplement it with specialized research, primarily at academic institutions. In June 1941, NDRC was replaced by a more powerful office called the Office of Scientific Research and Development (OSRD), also chaired by Dr. Bush. A few weeks later, the Navy established a counterpart organization known as the Office of the Coordinator of Research and Development (OCRD), chaired by Dr. Jerome Hunsaker. The charters of both organizations included significant responsibilities to fund defense-related R&D by both industry and academia. This was the first time in US history that the Federal Government had funded defense-related research at academic institutions.

Under the direction of NDRC, and then OSRD, annual Federal R&D expenditures climbed from a little more than $81M in 1940 to over $706M in 1944. An indication of the importance of OSRD is that Dr. Bush reported directly to the President of the United States and was, in essence, the President's science advisor. The extraordinary advances in military technology that took place in the US between 1942 and 1945 were due in large measure to the existence of OSRD and the cooperative spirit it engendered among government, academia, and industry.

As World War II was coming to a close, several Naval Reserve officers who worked on the Navy OCRD staff concluded that a more permanent arrangement was needed to ensure the continued flow of the latest technology into naval systems. These officers, known as the "Bird Dogs,"[6] drafted the legislation that ultimately became law in August 1946 as PL 79-588, creating the Office of Naval Research. For several years thereafter, ONR was essentially the only Federal sponsor of research in the US. After several years of debate over the merits of unfettered government-sponsored research, the National Science Foundation was established in 1950 and became the second such sponsor. Other funding agencies soon followed. However, the world leadership of the US in basic research in the decade following World War II has been largely credited by many experts to the timely and effective work of ONR.[6]

Unlike NSF, ONR has always been a *mission-based* funding agency. What this means is that while ONR (like NSF) strives to fund only research that is of superior scientific quality, the research must *also* have relevance to US Navy problems, known or anticipated. Admittedly, that relevance can be rather far in the future and can even be difficult to discern at the time—the full payoff for such investments often is not realized for 20 years or more. For example, many of the exotic materials used in today's ships, submarines, military aircraft, and weapons systems are derived from materials research funded by ONR 20 or even 30 years ago. Nevertheless, naval relevance has always been a significant driver of all of ONR's investment decisions.

Given this situation, ONR has historically attempted to maintain at least some presence in nearly *all* research areas of potential Navy interest. Thus, virtually from the beginning, ONR has sponsored work in such areas as materials, electronics, mathematics, physics, chemistry, oceanography, meteorology, underwater acoustics, electromagnetic propagation, mechanics, training, and biomedical studies. Although the ONR level of investment in each research area often rises and falls in response to such factors as the perceived threat environment, the availability of funds, and the level of investment by others, ONR has remained a continuous (albeit sometimes a minor) player in virtually all research areas of Navy interest for its full 50-year history. In addition (and most significantly for this study), during its first 25 years, it remained a *major* player in the ocean environmental sciences: oceanography, meteorology, marine geology and geophysics, underwater acoustics, marine chemistry, ocean sensing and measurement technology, Arctic environmental studies, etc.

This situation began to change in the late 1960s. Beginning with reductions imposed to support the Vietnam War, the Navy Basic Research (6.1) and Exploratory Development (6.2) budgets have declined to less than 37% of their former buying power over the past 35 years (Figure 1). Ocean-related research areas that were virtually "owned" by the Navy in the 1950s and 1960s now receive very significant support from NSF and other sponsors such as NOAA. This trend is shown in Figure 2, which illustrates the shift in ocean science sponsorship that took place from Fiscal Years 1967 through 1977. During that period, ONR's share of the Federal extramural (i.e., not spent at in-house laboratories like NRL) research base in the ocean sciences (including ocean acoustics) dropped from 44% to 18%, while NSF's grew from 28% to 50%. ONR's contributions to the field bottomed out in Fiscal Year 1976 and then began a mild recovery (in terms of current-year dollars) that continued until the mid-1980s. Figure 3 shows the total investment in the ocean sciences for several funding agencies between FY66 and FY90. The data shown for the Navy probably consist almost entirely of ONR funds, though the NSF database from which these data were derived does not identify how much came from ONR. Note that the funding amounts plotted in Figure 3 include money provided to in-house laboratories like NRL.

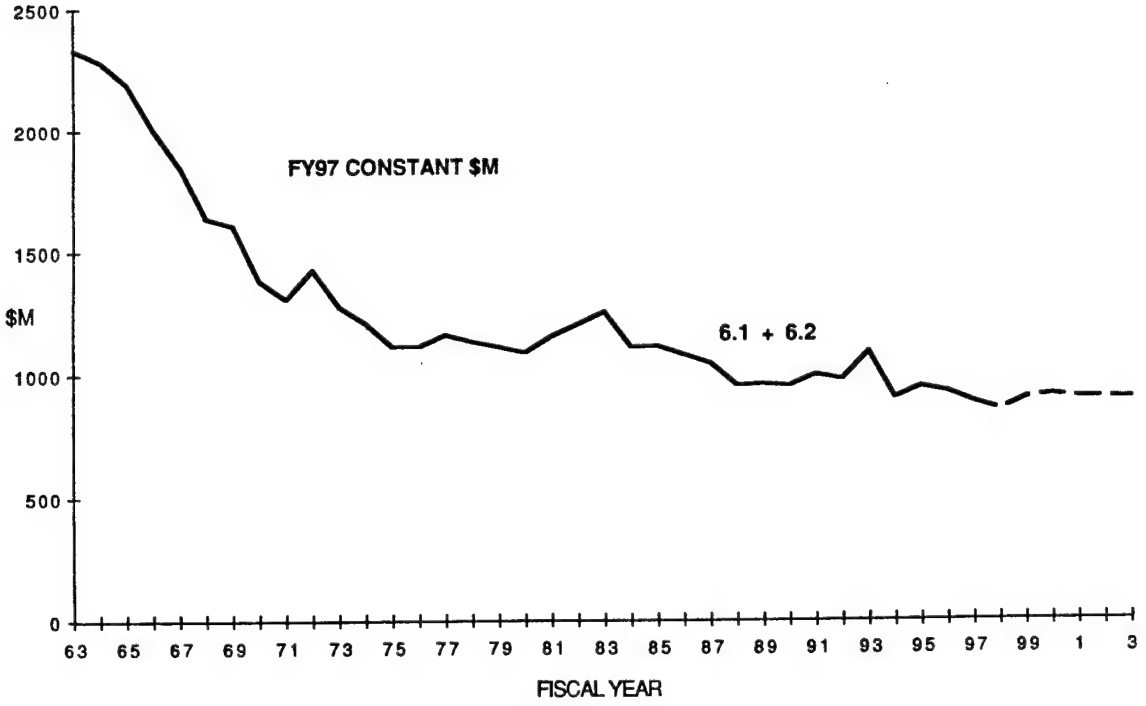


Figure 1. Department of the Navy Basic Research and Exploratory Development funding, FY63–03.

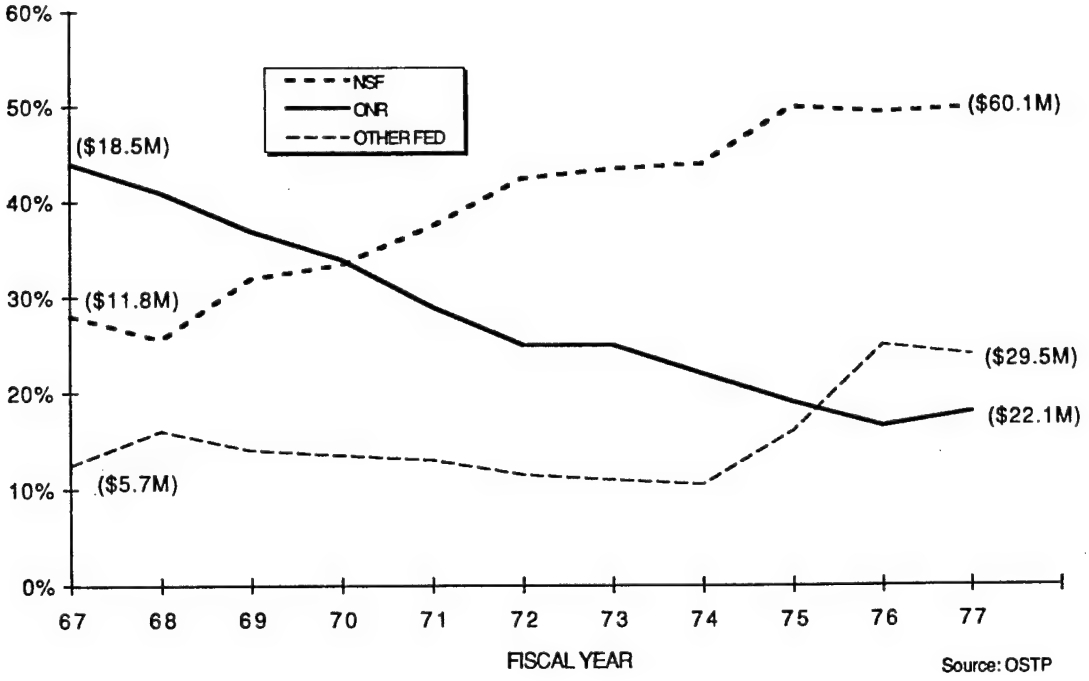


Figure 2. Extramural ocean sciences funding by source, FY67–77 (percent participation).

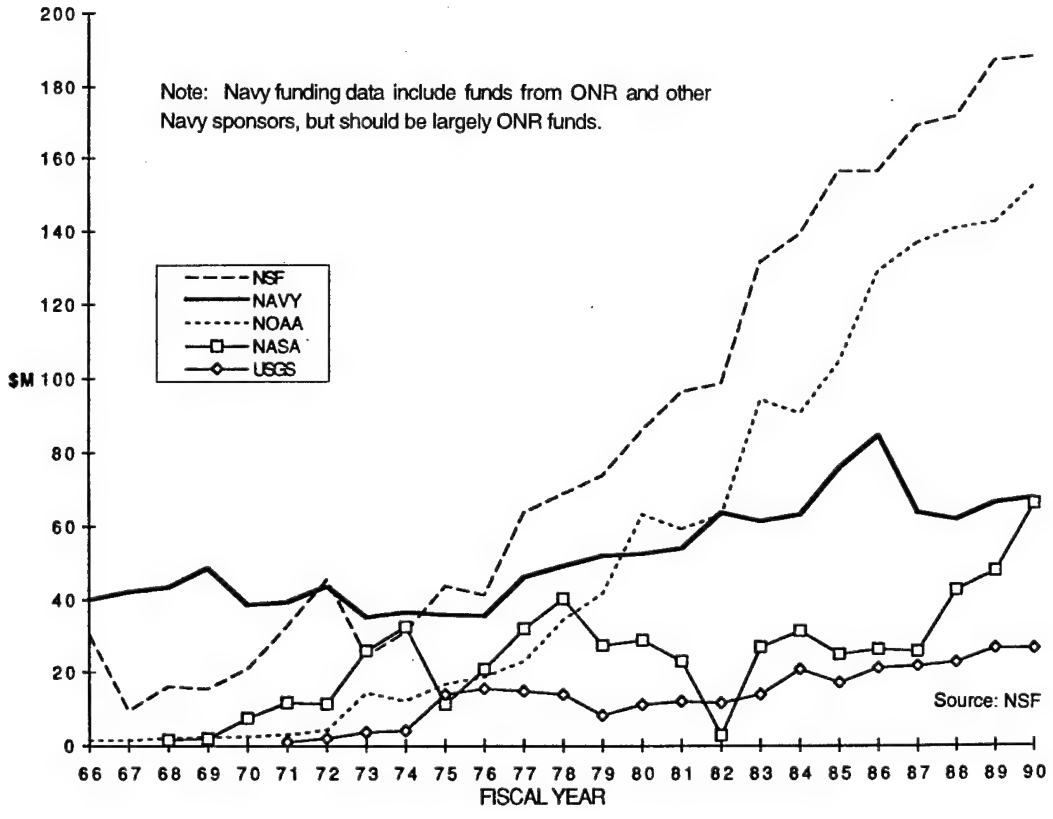


Figure 3. Total ocean sciences funding by source, FY66–90.

Figure 4 shows the more recent contributions of ONR, NSF, and other funding agencies to Federal extramural funding of the ocean sciences. While every agency's share has fluctuated somewhat over the years, the ONR component has stayed around 20% most of the time. Figure 5 is a 32-year plot of total ONR Basic Research funding in the ocean sciences (including funds provided to NRL and other Navy in-house activities) which clearly shows the recent downturn of buying power in these accounts. Figures 2 through 5 are provided to illustrate the magnitude and recent history of ONR funding in the ocean sciences. The data included in these plots come from a variety of sources and, not surprisingly, do not agree exactly (most of the major differences are probably due to the use of different definitions when the data were obtained). Nevertheless, most of the significant peaks and valleys line up rather well.

During the 1980s, the Navy reorganized its administration of Science and Technology (S&T) programs (which then included fund categories 6.1, 6.2, and 6.3A) several times. The Office of Naval Technology (ONT) was created to manage Exploratory Development programs (6.2), was placed under the command of the Chief of Naval Research (CNR), and was co-located with ONR. Later, the Office of Advanced Technology was established to administer the distribution of Advanced Development (6.3A) funds, though much of the decision making regarding the disposition of these funds remained elsewhere. Even though ONR did not control all of these funds directly, it was not unusual for all S&T programs in a single technical area to be reviewed together in order to provide an integrated view of these related efforts.

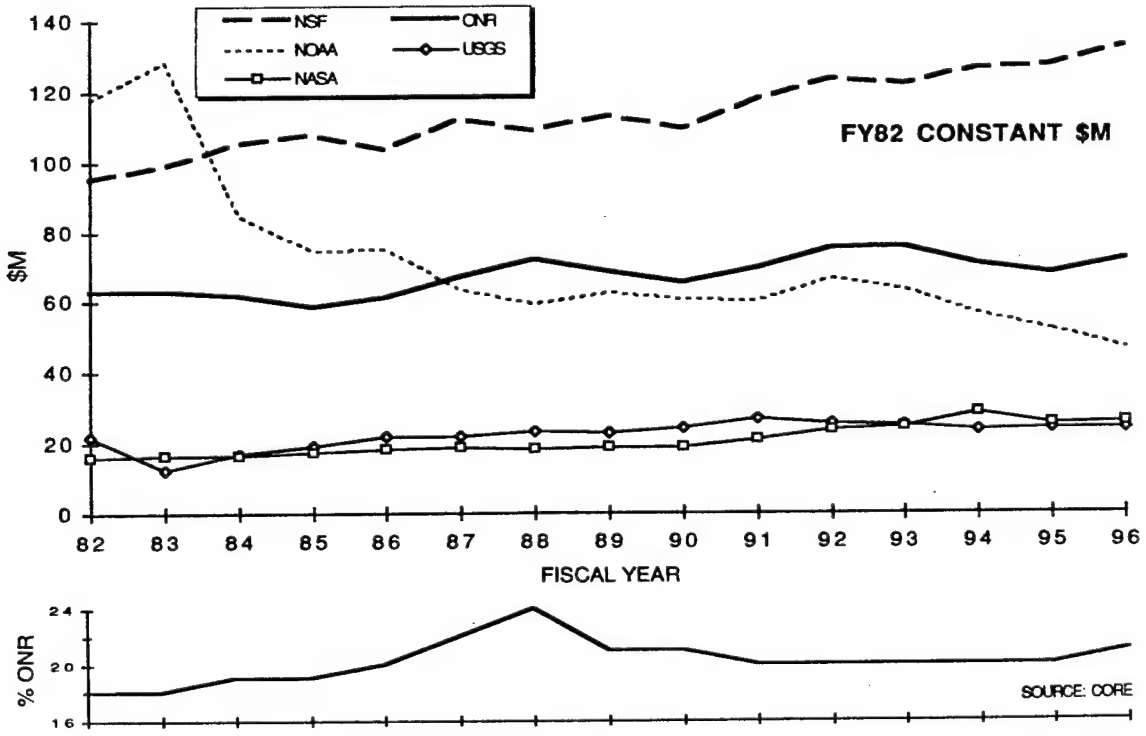
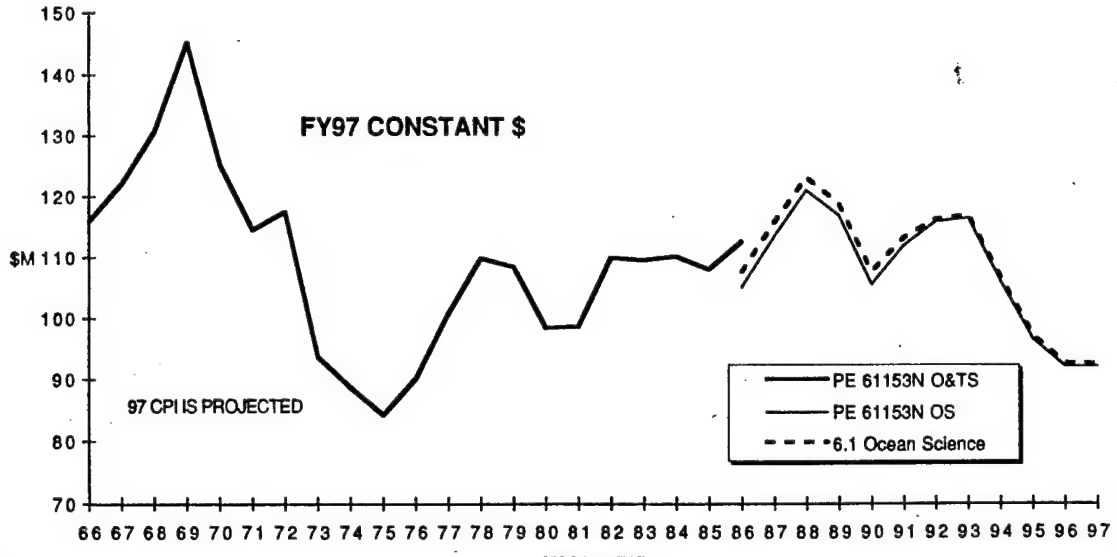


Figure 4. Extramural ocean sciences funding by source, FY82–96.



Notes:

PE 61153N Oceanography and Terrestrial Sciences - Includes data from the two predecessors to the PE 61153N Ocean Science account. A reorganization in FY86 placed all of Oceanography and most of Terrestrial Sciences in the new Ocean Science account.
PE 61153N Ocean Science - Includes all funds spent through the Contract Research Program (primarily at universities) and at NRL. These data are approximately equivalent to the oceanography component of the Oceanography and Terrestrial Sciences accounts that existed prior to FY86.
6.1 Ocean Science - Includes all Basic Research funding invested in this area, including that spent at the Naval Warfare Centers and their predecessors.

Figure 5. Navy Basic Research funding in ocean sciences, FY66–97.

Improvements in Soviet submarine technology became apparent to the Navy in the mid-1980s, increasing interest in ASW R&D in both ONR and the Navy as a whole. Despite years of investment in nonacoustic ASW R&D programs, acoustic sensors remained the only viable mechanism for detecting, identifying, and tracking potentially hostile submarines. Faced with an expanding submarine threat and limited resources, in 1986 ONR asked the Naval Studies Board to identify and recommend "significant and promising areas for underwater acoustics research." In its report on this study,[1] the NSB Panel on Research Opportunities in Underwater Acoustics made the following statement:

> In making recommendations the panel is aware that ONR is the primary source of support for research in underwater acoustics. The Division of Ocean Sciences of the National Science Foundation does not have a program in underwater acoustics, although it has accepted tomography as a potential tool for the ocean scientist. However, ONR maintains the only real commitment to ocean acoustics, and therefore is almost single-handedly responsible for the health, strength, and growth of this important discipline. Considering the nature of the threat, the urgent need for rapid and significant advances in fleet operations and tactics that account for ocean variability, and the need for fleet quieting and improved systems for detection, classification, and localization, the responsibility is great. It must be handled with imagination, a commitment to excellent programs and scientists, and an adequate and continuing financial base. While some of these issues are not the immediate purview of this panel, it will be impossible for ONR to capitalize on research opportunities unless these items are given priority. Of particular concern is the level of commitment; it may be insufficient to maintain a viable research effort within the academic scientific community. Experiment and validation are still fundamental parts of good science, and hence

> good underwater acoustics, yet ONR supports few academic laboratories capable of mounting effective acoustics field programs. We sense that academic ocean acoustics is beginning to lose the benefits of a young, vigorous research constituency, and we discern a lack of enthusiasm for choosing this career path. These are serious problems that must be addressed if ONR is to take pride in the further development of an underwater acoustics research community whose past contributions have been so important to the Navy and the nation, and whose future contributions are so vitally needed.

In 1988, ONR requested NSB to assist it in identifying promising basic research opportunities in the area of general physics. This panel reviewed ONR and NRL "research in physics and its direct offshoots." Among the programs reviewed were physical acoustics and the "physics of acoustics," which included some aspects of underwater acoustics. In its report[2] the NSB Panel on Research Opportunities in General Physics included the following statement:

> The least vulnerable to hostile attack of the defense triad of the United States is the submarine fleet. Of prime importance in preserving this capability is detection of hostile underwater vehicles and mines, and protection from detection of our own vehicles. The principal physical means of detection and location is the use of acoustics.
>
> The panel believes that the health of the nation's scientific enterprise in acoustics will ultimately determine our ability to assess and reduce both the threat of Soviet submarines and the vulnerability of US submarines. Recent Soviet accomplishments in achievement of quiet submarines have reduced our relative advantage.
>
> The panel believes that it is the Navy's unique responsibility to maintain the health of the nation's scientific effort in acoustics. No other federal agency currently has this charge or is likely to in the future. The panel recognizes the support for basic research in the physics of acoustics within the ONR physics core Contract Research Program. It also recognizes the core program in acoustics at the NRL for support of signal processing research, and the underwater acoustics core program for support of underwater acoustic transducer and measurement technology and of propagation studies.
>
> However, the panel is deeply concerned that the Navy has not assumed a national responsibility for the health of basic research in the physics of acoustics. Within the ONR Physics Division core program, physical acoustics is less than 10 percent of the total program....
>
> The panel also notes that the academic community in the physics of acoustics in the United States remains relatively small and that its research continues to be significantly dependent on Navy support. It is the view of the panel that the academic community in the physics of acoustics is too small to serve the national interest. It needs increased vigor and an expansion in numbers.
>
> An expansion of funding is necessary for long-term basic research. Modernization of experimental and computational equipment is needed to upgrade the quantity and quality of research conducted by the relatively few experts in the field and to attract capable students. University programs in the physics of acoustics are the major factor

> in the production of scientists and engineers who will fill the acoustics research and development needs of academic, Navy, and industrial establishments.
>
> The panel recommends that the Navy assume primary responsibility for the support of broad long-term basic research in the physics of acoustics. It is the only means by which a broad base of expertise can be established that would be sufficiently flexible and of sufficient depth to significantly advance the Navy's program in submarine detection and protection. Unexpected developments in physics abound in every field. Methods not even thought of now may turn out to be essential components for the solution of practical problems in the future. The Navy must have available a cadre of research personnel who have worked at the frontiers of the physics of acoustics and who can be called on to address problems in an innovative manner. A class of graduates must be available to serve as key acoustic personnel for the Navy.

ONR took action on these recommendations and significantly increased funding for basic research in underwater acoustics beginning in FY89. However, shortly after these words were written, the Cold War came to an end and the DOD budget started a significant decline. Navy budgets for S&T programs have shared in these reductions, which now have reversed all of the progress made a decade ago in enhancing the acoustics research base. The amounts of funding available for research in ocean/underwater acoustics and the physics of acoustics have now been reduced well below the levels already deemed by the two NSB panels to be inadequate. Figure 6 displays the amount of 6.1 funding available for ocean acoustics (only) since FY84. Note that a significant portion of the large increases evident during FY89 through FY94 were due to a Special Research Program (SRP) that focused on studying the reverberation of acoustic energy from the ocean surface and bottom. This program was developed specifically to support the deployment of the Navy's first low-frequency active surveillance systems. Although the SRP funds did indeed (temporarily) add to the amount available for ocean acoustics research, they were narrowly focused on SRP objectives and were not available to any other part of the ONR acoustics program.

The impact of the funding reductions displayed in Figure 6 was magnified even further by the contemporaneous end of the Acoustic Thermometry for Ocean Climate (ATOC) program. ATOC was focused on determining the usefulness of acoustic tomography for measuring global ocean temperatures and funded ocean acousticians at many of the institutions included in this study. Most ATOC funds were provided by the Defense Advanced Research Projects Agency (DARPA) and thus are not displayed in Figure 6.

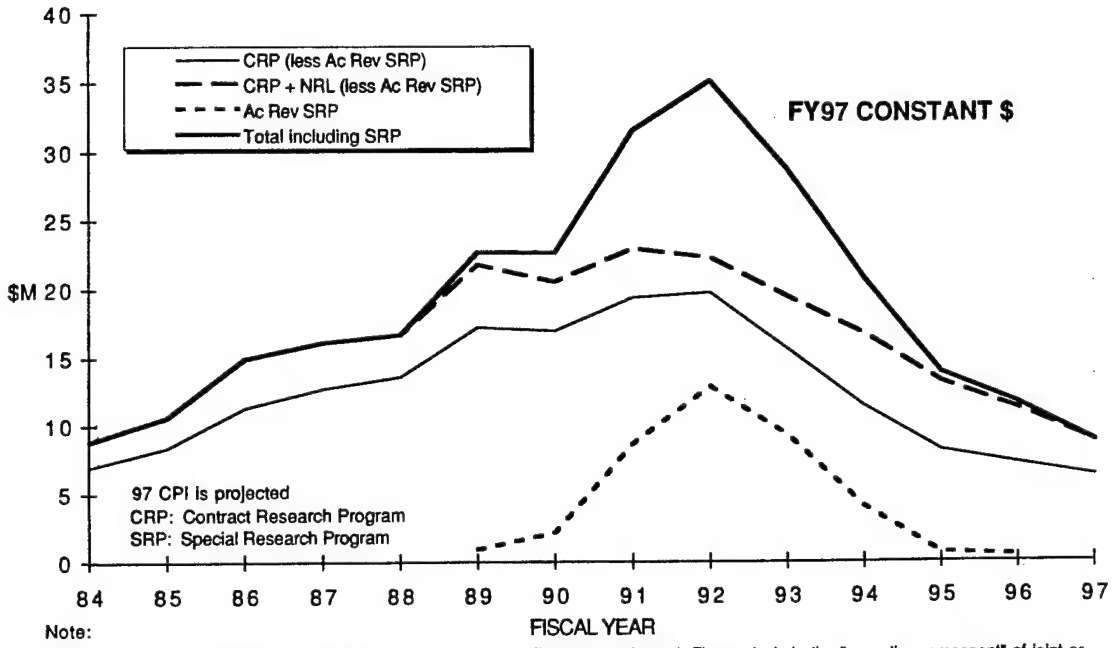


Figure 6. Navy Basic Research funding in ocean acoustics, FY84–97.

2. GENESIS AND DESCRIPTION OF THIS STUDY

ONR management has watched these and related trends with increasing concern. The shift from a "blue-water" (open-ocean) to a "brown-water" (littoral) threat environment has resulted in reduced priorities and disproportionately large reductions in submarine and ASW R&D. Yet ONR continues to have a responsibility to the Navy of the future to look beyond the current threat environment to a time when ocean acoustics might be the most important component of the Navy's tool kit. The US has never been able to predict what would be needed for the next war.[4]

Although the Cold War is over, the submarine threat is expected to increase significantly over the next two decades. The only part of the Russian Navy that is still functioning is its submarine fleet. China, Iran, and a number of other potential adversaries have also chosen the submarine as the capital ship of their navies. Their intent is not to use the submarine to win a war (as did the US and USSR), but rather as a strategic terror threat to exert influence over their adversaries, including the US and the Western powers. Modern diesel submarines (e.g., the German Type 209 and the Russian Kilo) are readily available on the world weapons market and are vastly simpler to operate with unsophisticated crews than the nuclear boats employed by the great powers. They are also very quiet and are difficult to detect with current ASW systems, especially in confined, relatively shallow areas. Nevertheless, in the current, severely constrained budgetary environment, ASW has a low priority in the Navy, and this fact is reflected in the 6.1 investment strategy. Unfortunately, when the hostile submarine threat reappears, it may be difficult to reconstitute the research base and the supply of young ocean acousticians, many of whom will have left the field for greener pastures with more promising budgets. Some in the ocean community have estimated that it could take a decade or more to recover from these reductions if the current trend is permitted to continue for too long.

Confronted with the above situation and concerned that it was failing to fulfill its national responsibility to maintain the ocean acoustics S&T base, ONR requested the Applied Physics Laboratory at the University of Washington (APL-UW) to assess the probable health of ocean acoustics S&T in the US now and into the 21st century. Specifically, the study was to

- Determine if the pipeline of young ocean acousticians is robust enough to support long-term Navy needs.
- Determine if the shrinking market is creating an imbalance among the various components (e.g., students, university researchers, and in-house performers/managers/keepers of corporate knowledge) of the Navy ocean acoustics community.

- Determine if the current situation is likely to provide a continuing supply of up-and-coming superstars.
- Address other items and issues as they arose.

The study approach was to visit a limited number of laboratories and research institutions and interview leading Navy-sponsored ocean acousticians to obtain data and their views on the health of this important Navy discipline. Although the health of any scientific discipline in the US depends to a significant degree on the level of research funding, an attempt was made in this study to separate the effect of reduced funding from other factors that might be affecting the health of ocean acoustics. In particular, a special effort was made to identify any additional actions that might be taken to alleviate any anticipated future shortfalls in the pool of ocean acoustician talent. It was hoped that the final product would include a set of findings, observations, data, and possible initiatives that could be used by ONR to assist in decision making.

An advisory panel was established to approve the approach and review the final report. The members of the advisory panel were

- Arthur Baggeroer, MIT
- John Orcutt, Scripps Institution of Oceanography (SIO)
- Robert Spindel, APL-UW.

Approximately 20 leading ocean acousticians from nine organizations were personally interviewed, and a number of others participated in round-table discussions held at some of the institutions. In addition, at the seven universities visited as a part of this study, some 30 graduate students and members of the postdoctoral staff were interviewed privately to learn more about their expectations and why they chose acoustics as their field of study. The organizations visited were

- Massachusetts Institute of Technology
- University of Miami (U/Miami)
- Applied Research Laboratory, Pennsylvania State University (ARL-PSU)
- University of Rhode Island (URI)
- Scripps Institution of Oceanography
- Applied Physics Laboratory, University of Washington
- Woods Hole Oceanographic Institution (WHOI)
- Naval Research Laboratory
- Naval Underwater Warfare Center (NUWC).

There are obviously many other laboratories and institutions that are conducting ocean acoustics research and/or educating acousticians. However, it was not possible to visit every organization participating in the ONR acoustics research program, and it was felt that those selected would provide data that would be applicable to the others as well. Appendix B lists the individuals interviewed as a part of this study. These individuals and

institutions were intended to be representative of the acoustics community as a whole and were selected in an attempt to provide a balanced view among

- The academic institutions that produce most of the American citizens with degrees in acoustics and related fields
- Major academic and government employers of ocean acousticians engaged in R&D
- Organizations that are primarily engaged in research and those performing higher categories of R&D and fleet-support work.

Those interviewed were not only asked for their professional views on the health of ocean acoustics but were requested to provide any organizational demographic data that were available to identify long-term trends and determine if, as expected, the population of acousticians is aging and few younger replacements are entering the field. A call for data (Appendix C) was used to elicit this information. Copies of the data call were also sent to several other institutions with smaller programs in acoustics or in cases where schedules did not permit personal interviews. Informal phone interviews were conducted with acousticians at some of these institutions. The institutions and organizations submitting data or information but not actually visited include

- University of California, Santa Cruz (UCSC)
- Georgia Institute of Technology
- Applied Research Laboratories, University of Texas (ARL:UT)
- Washington State University (WSU)
- Naval Postgraduate School (NPS)
- Office of the Chief of Naval Operations (Submarine Security Program, N875)
- Naval Oceanographic Office (NAVOCEANO).

Other indicators, such as Acoustical Society of America (ASA) membership data and the number of papers on underwater acoustics appearing in the *Journal of the Acoustical Society of America* (*JASA*), were examined to identify any useful trends.

3. DISCUSSION OF VISIT SITES

The organizations listed in the previous section are obviously a rather heterogeneous group; in fact, they were chosen to get a balanced view of the situation from as many perspectives as possible. As organizations, one of the few things they have in common is an interest in ocean acoustics. What may not be quite as obvious is that the academic institutions on the list are very different from each other as well.

For example, most of the professionals that the Navy (and most of the universities) would call "ocean acousticians" are actually receiving degrees in something else. While the exact words on these advanced degrees may not matter much, it's probably worth noting that they include Applied Marine Physics, Applied Ocean Science, Oceanography, Earth Science, Electrical Engineering, Ocean Engineering, Geophysics, Physics, and others as well.

Another example is the fact that four schools maintain semi-autonomous, self-contained facilities—ARL:UT, ARL-PSU, APL-UW, and the Marine Physical Laboratory (MPL) of SIO—that make it easier for them to perform classified (primarily Navy) work. Predecessors of all four of these facilities, often simply refrred to as "ARLs," were established during World War II expressly to support Navy R&D requirements. Although several of the other academic institutions can also conduct classified work (Navy Basic Research work is all unclassified, but some Exploratory Development work is classified), they do not maintain separate facilities for doing so. The degree to which ARL staff members participate in teaching, and the degree to which graduate students and postdocs participate in ARL work, varies considerably from site to site. The reasons vary, but include the distribution of funding (6.1/6.2/6.3/etc.), proximity to the campus, perceptions by students about their chances of future employment, tradition and culture, and perhaps other factors as well. In 1979, ONR established a special "ARL Project" at APL-UW, ARL:UT, ARL-PSU, and MPL-SIO to encourage collaborative research between the ARLs and the researchers in the academic departments at their respective universities. This program continues to be an excellent mechanism for improving the ties between the academic and Navy-funded sides of these four schools, but is currently funded at the relatively modest level of about $375K per year per university.

The ARLs differ from each other in other significant ways as well. Compared to 20 years ago, the proportion of 6.1 funds has climbed significantly at APL-UW and MPL-SIO and declined by similar amounts at ARL-PSU and ARL:UT. The directors of all four laboratories stated that they considered these trends to be unhealthy in the long run and to be something that they would like to reverse.

There are also rather significant differences between the curricula available at the more important acoustics schools. Most of those visited (and most of those receiving more than $500K a year from the ONR 6.1 acoustics budget) are actually oceanography schools that offer differing numbers of acoustics courses. Some actually offer very few formal courses in acoustics—their training in acoustics is actually provided through

participation by graduate students in at-sea experiments, equipment preparation, signal processing algorithm development, and data analysis. A number of these schools (WHOI, SIO, UW, U/Miami) have a large investment in oceanographic infrastructure and a long sea-going tradition, and have been doing ocean acoustics R&D work for the Navy for 30 years or more.

Despite having little or no oceanographic capability, a number of other Navy-funded research institutions nevertheless have a long history of producing world-class acousticians in their physics, engineering, or geophysics curricula. These include MIT, UCSC, Georgia Tech, Catholic University, the University of Michigan, Renssalaer Polytechnic Institute, and the University of Wisconsin.

At least one of ONR's important acoustics research organizations, however, is stamped from a different mold—PSU. Penn State offers a graduate program in acoustics as a part of its College of Engineering and is the only US institution that offers both M.S. and Ph.D. degrees in acoustics. About 100 students (plus 30 continuing education students) are enrolled in the PSU program, considerably more than at any of the other institutions examined. Course work is not focused exclusively on ocean/underwater acoustics, but includes physical acoustics, vibration, noise control, etc. Penn State established its program at the request of the Navy in 1965 and continues to be a major player in Navy acoustics R&D.

Another singular example is WHOI, which for many years was an institution dedicated exclusively to oceanographic research, with no educational program responsibilities. Since 1968, however, WHOI has collaborated with MIT to offer a joint program in Oceanography/Applied Ocean Science and Engineering, with MIT faculty and WHOI researchers both teaching courses and conducting research at sea.

The point of this is not to identify PSU, WHOI, or MIT for special consideration, but rather to note that the diversity of ONR's performers of acoustics research makes a one-size-fits-all solution very difficult. Over the past 50 years, the Navy and ONR have created a diverse family of educational and acoustics research institutions, each with its own unique strengths and capabilities. The recent reductions in acoustics research funding are affecting each in its own way, and it is important that any corrective action be designed to retain these capabilities as national assets.

4. PRINCIPAL FINDINGS

In 1986 and 1988, NSB panels declared that the level of investment in ocean acoustics and the physics of acoustics was inadequate to maintain the academic research base in this critically important and Navy-unique area. As shown by Figure 5, the amount of ocean acoustics Basic Research funding has declined even further, by about 50%, since FY88. While there have also been very significant reductions in higher categories of ocean acoustics R&D funding, *it is generally the 6.1 money that supports graduate students and postdocs and produces the research papers and theses.* In fact, a senior scientist at one institution said, "like it or not, 6.1 money *buys* graduate students." (And they're not cheap, either—the overall cost of a typical five-to-six-year residency for a Ph.D. is $150K to $250K.) As a result, one would expect that reductions in 6.1 funding for ocean acoustics would produce a commensurate reduction in the production of graduate students and postdocs in this technical area. The study found that this was, in fact, the case. ONR investments in the area of ocean acoustics have a direct and immediate impact on both the health of the research programs in this field and the number of the graduate students studying it. ONR funding levels also strongly influence other, related matters such as institutional investments in infrastructure and membership in the Acoustical Society of America.

As a part of this study, each of the institutions listed in the previous section was requested (Appendix C) to provide information regarding their levels of funding, numbers of students, and other parameters that would provide a measure of the strength of their ocean acoustics programs. Few institutions were able to obtain verifiable data for all of the items on the list, so no institution-to-institution comparisons were possible. However, virtually all reported significant reductions in both funding and the production of ocean acoustics graduate students over the past few years. The magnitude and onset of these reductions varied somewhat, depending on a variety of factors (e.g., a few had modest amounts of ATOC or 6.1 Acoustic Reverberation SRP funds until recently), but the general trend is now consistent and essentially universal in the community. The institutions that began significant declines several years ago are now seeing a rather serious decline in the number of students and even faculty in the ocean acoustics area. Organizations that have relatively strong programs in related areas (e.g., UW in medical acoustics and PSU in other areas of acoustics) are losing students to those areas, even though they may be maintaining overall enrollments in the general area of acoustics.

While the effects of these reductions vary quite a bit from institution to institution, it would be difficult to overstate the seriousness of the problem, especially as it pertains to the long-term future of Navy ocean acoustics R&D. The organizations that perform most of the Navy-sponsored ocean acoustics R&D, both academic and Navy-owned, are slowly losing staff as their budgets decline. In addition, the average age of their staff members is slowly increasing because of a lack of recruiting. At some point, however, their staff sizes and their budgets in this field will reach equilibrium, and limited

recruiting will recommence. Given this situation, the current production of ocean acousticians is probably adequate to support the *current*, reduced level of Navy system development in this area. However, it is *not* adequate to support a level of ocean acoustics R&D and ASW system development that is significantly greater than the current (low) level of investment.

The following paragraphs summarize, in order of relative importance, some of the specific findings of this study. While some conclusions do not pertain directly to the process of educating acousticians, it must be borne in mind that the health of the educational process depends on the vitality of the research programs at the educational institutions that train them, and at the laboratories that eventually employ them.

1. With a few isolated exceptions here and there, nearly every indicator of the health of the ocean acoustics research base in the US is pointing downward. The reasons for this trend were adequately summarized by the NSB in 1986 and 1988: "ONR maintains the only real commitment to ocean acoustics, and therefore is almost single-handedly responsible for the health, strength, and growth of this important discipline,"[1] and "[t]he panel believes that it is the Navy's unique responsibility to maintain the health of the nation's scientific effort in acoustics. No other federal agency currently has this charge or is likely to in the future."[2] This situation remains unchanged today. Despite the fact that the past 10 years have demonstrated that the field of ocean acoustics has great potential as a powerful tool in oceanography and such nondefense-related areas as global climate change, NSF and the other sponsors of ocean-related research remain very reluctant to fund any projects that require investments in acoustic measurements or instrumentation. The reasons for this reluctance probably have more to do with politics than science, especially given the potentially usefulness of the field to other funding agencies. Acoustic thermometry, for example, should be useful to NOAA in executing its responsibilities to monitor global climate and would also have application to NSF's physical oceanography programs. Other aspects of ocean acoustics should be of value to NOAA programs that monitor marine mammals and fish stocks, to DOE in executing its responsibilities to monitor compliance with the Comprehensive Test Ban Treaty, and to NSF research in the areas of crustal dynamics and earthquake mapping. Nevertheless, with the possible exception of occasional support from DARPA, ONR remains the only sponsor of ocean acoustics research, and the health of the ocean acoustics community in the US improves and declines with the ONR budget for research in this area. *Thus, the recent decline in the vitality of the ocean acoustics research community in the US is a direct result of recent ONR funding reductions in this discipline, and only an increase in the level of funding in this area will really cure the problem.* Over the long term, the current level of Federal support for acoustics research is almost certainly inadequate to maintain

the production of sufficient acousticians to respond to current and future Navy/DOD needs. On the other hand, the current level of research funding may be just about right to maintain the small trickle of ocean acousticians necessary to support the Navy's current needs in this time of reduced priorities and budgets. Increasing the level of funding in ocean acoustics research will surely increase the number of graduate students in the area, but most will probably end up taking jobs in other areas (see discussion of job opportunities below). This, however, may be an acceptable solution. At least the nation will have a pool of trained experts to draw upon in the future if the Navy, its contractors, or academia need to hire them in a time of emergency. Clearly (as shown by Figures 1 and 4), the budget pressures on ONR are real. Nevertheless, there are other Federal sponsors for most of the research fields in the ONR portfolio, but there are none for ocean acoustics. For the foreseeable future, ocean acoustics will remain the principal technology used to detect hostile submarines and to ensure the security of our tactical and strategic submarine forces. This study concludes that the strength of this field, virtually the only discipline entrusted entirely to ONR's care, is not being sustained.

2. Despite these problems, acoustic ASW may very well be on the verge of a real revolution in capability, brought about by extraordinary increases in processing power, a variety of new sensors, a greatly improved understanding of ocean coherence, and advances in communications and data distribution capabilities. Thus, at the very time when acoustic ASW may be able to make breakthroughs comparable to those made in the 1940s, '50s, and '60s, funding levels for basic research in underwater acoustics are close to a 50-year low.

3. Nearly all of the institutions are struggling to maintain a sea-going capability. The number of field experiments is down, the number of days at sea per year is down, investments in new equipment are down dramatically, and the cadre of ocean-savvy engineers and technicians is slowly eroding away without being replaced (one example: the SIO experimental group is half the size it was 10 years ago, and contains no young people). Although many of these individuals are college educated, their at-sea skills generally were "learned by doing," i.e., gained by years of going to sea on ocean acoustics research cruises. These are the people who ensure that equipment is deployed and recovered (with its data) routinely, reliably, and safely, under all environmental conditions. Declining to replace them in order to save money will inevitably turn out to be a false economy. Inexperienced or unqualified personnel can cause the failure of an experiment and the loss of its associated data (and maybe the hardware, too). Training the next generation of support personnel will turn out to be more costly in the long run if it is not started soon while some of the old hands still remain

aboard to serve as mentors for the next generation. Virtually every institution visited noted that once the pool of at-sea experience and knowledge represented by these highly skilled support personnel is lost, it will be virtually impossible to replace or reconstitute.

4. Textbooks and computer simulations can only teach students so much; ocean acousticians must have experience on field experiments. Yet several institutions reported that they were close to losing their ability to take students to sea. Because of lower funding, research cruises have been reduced in both frequency and duration. Even with the cost of ship time partly (or even largely) subsidized, at-sea experiments are still expensive, and funding never seems to be available to cover the cost of new general-purpose equipment or many of the other costs of mounting a field experiment. As a result, there was a view that for financial reasons, ONR was favoring proposals based on simulation and numerical modeling over those that required going to sea. Principal Investigators (PIs) in the NRL Acoustics Division noted that few recent job applicants with new degrees in acoustics had any sea-going experience. Most were essentially theoreticians. It is probably worth noting that most of today's senior acousticians were not trained in acoustics, but were educated in electrical or mechanical engineering, physics, or mathematics. They learned acoustics by going to sea, interpreting data, and archiving results in journals. While there are now a number of formal graduate programs in ocean acoustics, the opportunities for graduate students to acquire experimental skills are much more limited that they were when today's senior acousticians were trained. In fact, the institutions that continue to perform experimental oceanography (e.g., UW, SIO, and WHOI) are often looked upon as archaic financial burdens on the remainder of the community. For ocean acoustics to continue its contributions to national defense, action must be taken to maintain the nation's infrastructure for field experiments in ocean acoustics.

5. At most institutions, the average age of the ocean acousticians on their research and teaching staffs has shown a steady increase over the past 8 to 10 years owing to a lack of recruiting. Several organizations are in danger of losing virtually their whole acoustics research staff simultaneously. Figure 7, a plot of the average age of the scientists and engineers in the NRL Acoustics Division, is typical of most of the institutions visited. However, solving the problem at the Navy-owned laboratories/centers may be more difficult than at the academic institutions. A number of the students interviewed stated their belief that Federal Government positions had become undesirable as a result of uncompetitive salaries, arbitrary limits on promotions, and a lack of job security. While in some cases

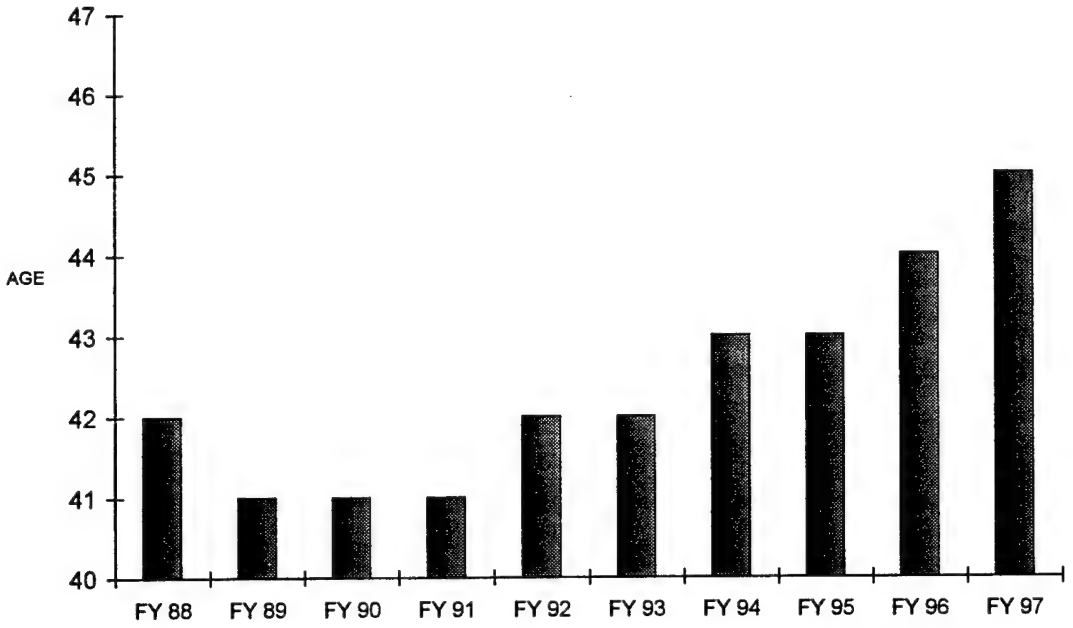


Figure 7. Average age of scientists and engineers at NRL's Acoustics Division.

the work might be more interesting than that encountered in industry, the Federal system is often regarded as hamstrung by Byzantine rules and regulations in such areas as personnel, travel, and procurement.

6. Both undergraduates and graduate students remain highly attuned to the identity of growth industries and the location of future job opportunities. Ocean acoustics is not viewed as being "sexy" like oceanography or lucrative like computer science, and is already having difficulty competing in the marketplace for the very best students. On the average, the best students will choose the fields with the best job prospects; this is borne out by the Graduate Record Exam scores of those applying for ONR fellowships. At this time, computer science is the growth area for graduate students, sometimes drawing more than 50% of all applicants to engineering curricula. Although this study focused primarily on the organizations that conduct most of the acoustic S&T work and educate the acousticians of the future, most ocean acoustics jobs are actually in industry. The following table displays the estimated distribution of underwater acousticians in the US and Canada in 1991, based on an ASA census[7]:

	Underwater Acoustics, Science	Underwater Acoustics, Engineering
Education	216	120
Government	304	296
Industry	338	844
Nonprofit	6	4
Consulting	27	41
Total	891	1305

The interviews with graduate students conducted for this study disclosed that none had selected ocean acoustics as their career choice while still undergraduates. Nearly all learned about it through some other means (job, oceanography school, Naval Academy, etc.) and decided that the area interested them. However, all were aware of the recent funding problems, and many were sufficiently concerned about their job prospects to be considering changing fields. One laboratory senior scientist stated it succinctly: "I worry a lot about whether I'm doing these kids a disservice by enticing them into going for an advanced degree in ocean acoustics. Are there going to be any jobs for them when they get finished?"

7. Funds available from internal sources at universities are generally awarded according to merit. Since the number of US citizens wishing to study ocean acoustics in graduate school is declining even faster than the number of applicants overall, much of this money goes to foreign students. In the past, many of these students remained in the US and became citizens; now, however, most return to their homelands after graduating. The US is, in effect, exporting its technology base.

8. The number of naval officers choosing to go for advanced degrees in the area of ocean acoustics, either at NPS or at other academic institutions, also appears to be in decline, apparently owing to budget pressures and the lack of career enhancement potential. Most of those still studying underwater acoustics are oceanography special duty officers (specialty area 1800). While 1800 officers with advanced degrees will remain essential, the Navy of the future will also need a cadre of technically trained unrestricted line officers who are capable of making difficult programmatic decisions regarding the development of high-technology systems. They may also be called upon to depend on such systems

in a wartime environment, where an understanding of their operation and limitations may mean the difference between success and failure.

9. To some extent, other fields of science (e.g., air acoustics and geophysical industry) provide a source from which acousticians could be drawn in an emergency, although some time might be required to familiarize those individuals with the then-current state of ocean acoustics R&D. In addition, individuals in related fields (electronic engineering, physics, signal processing) could be used to fill some acoustician positions; this has long been a tradition in the field anyway. Nonetheless, ONR still has a responsibility to maintain the national knowledge base in this critical area, similar to the Department of Energy's responsibilities regarding nuclear weapons (Sandia and Los Alamos National Laboratories) and the maintenance of submarine and nuclear propulsion expertise and technology (Electric Boat and Newport News Shipbuilding) by the Naval Sea Systems Command (NAVSEA).

10. Most of the academic institutions noted the relative prosperity of other areas of the Earth sciences, especially oceanography, compared to ocean acoustics. This prosperity draws both students and faculty away from acoustics. It is also noticed by university administrators, some of whom are threatening to reduce the number of acoustics faculty (MIT's acoustics faculty has already been reduced from four to three). The following very simple hypothetical example, while only approximate, is accurate to within an order of magnitude:

Beginning of Year	Acoustics	Oceanography
NSF funding:	$0	$100M
ONR funding:	$6M	$ 20M
Total available:	$6M	$120M

After ONR cut 10%	Acoustics	Oceanography
NSF funding:	$0	$100M
ONR funding:	$5.4M	$ 18M
Total available:	$5.4M	$118M
Percent reduction:	10%	1.7%

The obvious point here is that researchers in other areas can go to other sponsors for funding if their ONR programs get cut or eliminated. Ocean acousticians have no other alternatives. As the only sponsor of ocean acoustics research, ONR may have a responsibility to establish some minimum level of investment or to otherwise protect its ocean acoustics research program from repeated reductions.

11. Most PIs at the institutions visited expressed concern over the future of ocean/underwater acoustics, an area recognized as being of great importance to the Navy but of little importance to other sponsors of research. Much less concern was expressed about the future of structural or physical acoustics or the "physics of acoustics" (the term used in Ref. 2). Both NRL and NUWC conduct R&D in aspects of this discipline, and both felt that their needs for technical expertise were being met by academia. Both organizations noted that their requirements for physical acousticians were actually rather small and that many of the positions in their structural and physical acoustics groups were more appropriately filled by computer scientists, signal processors, electronic engineers, etc. As a result, this study did not find that the supply of physical and structural acousticians was inadequate to meet Navy requirements.

12. Positions as R&D performers seem to be drying up at about the same rate in both academic institutions and Navy organizations. Although the data vary widely, most of the institutions responding to the data call (Appendix C) report significantly fewer people engaged in ocean acoustics R&D than they had 10 years ago. Several have undergone significant reductions in force. Both the Navy and the academic institutions report similar trends, so it does not appear that one part of the R&D community is suffering more than another. In addition, there is anecdotal evidence that the employment of acousticians by Navy-sponsored industrial firms is also in decline as a result of the reductions in procurement and the higher categories of R&D funding. On the other hand, the number of ONR program managers engaged in managing ocean acoustics S&T funds may have increased, though the audit trail in this area is rather difficult to follow owing to reorganizations, funding transfers, etc.

13. The "ARL Project" in place at ARL:UT, ARL-PSU, APL-UW and MPL-SIO was considered to be a great success by all four laboratories (though the research it supports is not limited to acoustics). This effort, funded at about $1.5M a year (divided equally among the four laboratories), can be used to fund only research projects that involve collaboration between ARL PIs and faculty/graduate students at their respective universities. It was given very high marks both for the innovative qualities of the research it has funded and for the amount of "bang for the buck" it has given back to the Navy in terms of improving university/ARL collaboration.

14. The funding reductions have apparently spawned a decline in ocean acoustics-related papers published in the *Journal of the Acoustical Society of America*, as well as a decline in the number of ASA members expressing an interest in the area of underwater acoustics. The ASA maintains statistical data on the interests of their membership and on the contents of *JASA*, and some of these data were

graciously provided by the ASA for analysis in this study. All articles published in *JASA* are categorized by subject, e.g., mechanical vibration and shock, architectural acoustics, speech communication, underwater sound, etc. Figure 8 is a plot of the number of articles (and the number of pages in these articles) on underwater sound that have been published per year since 1976. These data correlate remarkably well (though with the expected slight lag of a year or so) with the data on ocean acoustics research funding presented in Figure 5. Obviously, ONR acoustics research money buys underwater acoustics research papers in *JASA*. Acoustical Society members also indicate their interest in up to three of 12 acoustical fields, one of which is Underwater Acoustics. An analysis of these data by the ASA[8] is presented in Figure 9. The number of ASA members selecting underwater acoustics as their primary area of interest appears to have peaked in 1989 and has been declining since then. However, much of this decline was probably because a new area called Acoustical Oceanography was added in 1991 and undoubtedly siphoned off some of those who had been selecting Underwater Acoustics as their first choice. Nevertheless, even when those selecting Underwater Acoustics as their second choice are included, the area still shows a decline over the last few years.

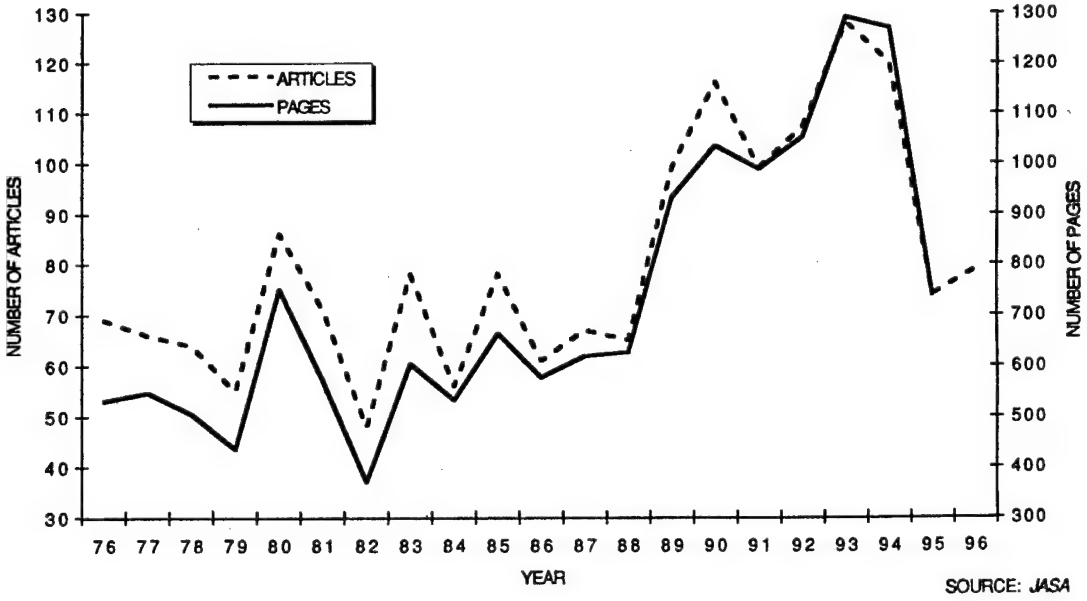


Figure 8. Number of underwater sound articles and pages published in the *Journal of the Acoustical Society of America.*

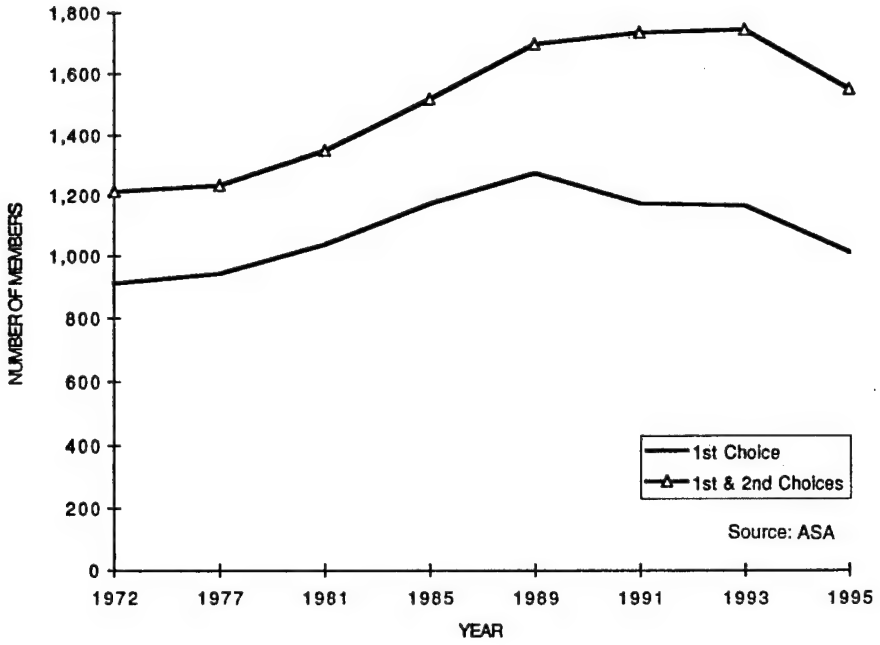


Figure 9. ASA members indicating underwater acoustics as their area of interest

15. Other ASA data seem to indicate that the number of academic institutions offering graduate degrees in ocean acoustics is also in decline. The ASA periodically publishes a "Directory of Graduate Education in Acoustics" which lists all academic institutions and their faculty that teach courses in acoustics. The 1984 issue listed 43 schools that offered courses in "Underwater Sound," while the 1997 version[9] lists only 30 (three others listed Acoustical Oceanography without also listing Underwater Sound). It would take considerably more research to determine if this was a real trend or just an unrelated bump in the data.

16. Nearly all of the PIs interviewed remarked that they were being forced to devote a continually increasing percentage of their time to preparing proposals, thereby leaving less of their time for conducting research and guiding students. (In fact, several graduate students stated that they had watched as their advisors continually searched for dollars, and it was making them re-think their career choice or consider a related area where the money pressure wasn't so severe, such as the geophysical industry or biomedical acoustics). One PI at APL-UW submitted just two proposals and was awarded $25M in grants from DARPA in the area of bioacoustics. The Army Medical Research and Materiel Command has a single Broad Agency Announcement on the street for $106M for breast cancer research. By contrast, in order to assemble a critical mass of dollars from ONR in the area of ocean acoustics, PIs are submitting one proposal for 6.1 money, an-

other (or more) for 6.2 money, another for DURIP* funding, another for AASERT† support, etc. From the perspective of the institutions, the response from ONR is often to fund one or two proposals at a subcritical level, perhaps $25K or $50K, and then suggest that these dollars be used to leverage other funds (e.g., from NSF or NOAA). The effect of this informal policy (if it *is* a policy) of many small grants to many institutions is to keep everybody alive but nobody happy. Also, leveraging doesn't work well if one is on the wrong end of the lever. Putting a greater percentage of the program into larger, "critical-mass" grants (of say, $250K or more) per year with at least a moral commitment to fund them for an additional year or years would provide continuity to the program and permit some of the institutions that are willing to make a long-term commitment to educating the Navy's acousticians of tomorrow to tackle some larger problems, renew infrastructure, take on an additional student or two, and possibly even conduct an additional research cruise. However, it is recognized that such an action would significantly reduce the amount of funding available for smaller, single-PI research projects.

17. A related problem is the apparent lack of an overall strategy to guide ONR's investments in ocean acoustics S&T (if there is one, it is has not been communicated to the institutions visited). Exploratory Development efforts in ocean acoustics, for example, are managed by a number of different ONR scientific officers, lack any unifying theme, and often are not well integrated with the Basic Research program. Multiple proposals to different scientific officers are the rule, not the exception. The end of the Cold War and the advances in technology have created new problems, but have also opened new opportunities. For example, the sensors on many of the new systems, especially those designed for shallow water, are expected to have large apertures and broad bandwidths. Active systems will operate at both much higher frequencies (e.g., 1–10 kHz for ASW and 10–200 kHz for weapons and mine warfare) and broader bandwidths (e.g., 1–10 kHz). Those interviewed at both NUWC and ARL-PSU noted the lack of an ONR 6.1 program in high-frequency ocean acoustics to respond to Navy priorities to support weapons programs or target and mine classification in the littoral environment. Others remarked on the lack of a coherent program to support the renewed interest in using very low frequencies for reconnaissance and submarine superiority. Principal investigators at nearly all of the institutions noted the lack of a significant investment of 6.1 and 6.2 funds to study vertical and horizontal coherence (e.g., what time-bandwidth product the medium can

* The Defense University Research Instrumentation Program provides grants for research equipment.

† The Augmentation Awards for Science and Engineering Research Training provides grants to support students who are US citizens to assist already-funded research projects.

support) and other performance measures for wideband, large-aperture sonars. Broadband and large-aperture sonars are expected to be around for many years to come, yet the research base to support such systems is lacking. This deficiency was felt to be particularly regrettable, given that computer power and mathematical modeling and measurement capabilities are now available to help sort out the data. Not all of the individuals interviewed may be aware of the OPNAV N091 role and the roundtable process that the Navy uses to identify R&D requirements. Nevertheless, those who were interviewed were virtually unanimous in their view that ONR was the only Navy organization with the technical expertise to set aside pressures to support existing systems, identify the acoustic systems that will be in place 20 or 30 years from now, analyze what environmental-acoustic understanding those systems will need to operate, and lay out the groundwork for a multiyear, multidisciplinary, multiinstitution research program that would provide such understanding.

18. Another, related problem is what might be characterized as program disruption: mid-year funding cuts, programs canceled in mid-stream, lengthy proposals being prepared for still-born programs, etc. While much of this turmoil is generated in the Navy and Office of the Secretary of Defense (OSD) bureaucracies well above ONR, more could probably be done to shield the institutions from its effects and prevent them from wasting as much time and effort on doomed programs. Nearly all of the institutions noted this problem, which they attributed at least in part to the lack of an overall ocean acoustics R&D investment strategy discussed previously.

Appendix D includes a number of quotations and observations from those interviewed for this study.

5. SELECTED SUGGESTIONS

The interviews with the study participants produced a number of suggestions for improving the long-term health of ocean acoustics in the US. While some would require a significant level of additional funding, many would need little or none at all.

Clearly, the most contentious ideas are those that relate to awarding a smaller number of much larger grants to a limited number of activities in order to maintain the ability to both educate students and maintain a sea-going infrastructure. Execution of such an idea, however, requires both a multiyear commitment to those institutions and a long-term goal upon which the research would be focused. (The Acoustic Reverberation SRP is an example of such an effort.) From the perspective of the institutions, both the commitment and the articulation of the goal are lacking at this time.

Also, implementation of such a plan might place the PIs at some of the smaller academic institutions (in terms of funding) at a severe disadvantage, since it might make it more difficult for them to obtain research funding in ocean acoustics. Several of these institutions (e.g., Wisconsin, Michigan, Catholic, Georgia Tech) have been producing world-class acousticians for the Navy for decades, and great care would have to be taken not to damage that productive relationship. Depending on what projects the PIs wished to propose, they might be forced to operate through one of the larger institutions (in a manner not yet defined) to carry out their research. They might see the proposal to significantly increase grant size and commit to multiyear programs as an attempt by the larger institutions to corner the market on Navy ocean acoustics research money. Unfortunately (as documented in the previous section), Navy ocean acoustics research is already losing some of its core capability and without additional funding cannot continue the current modus operandi indefinitely. For example, the program may no longer be able to support the proliferation of PIs (no matter how talented) at a continually growing list of institutions.

It is the conclusion of this study that ONR should take whatever actions are necessary to maintain the current level of graduate-level acoustics education in the US, even though many of the people thus educated will end up employed in related fields. ONR should work with the academic institutions to ensure the employability of these individuals, who will serve as a "skills bank" that can be called upon in a future emergency.

Several specific suggestions to help execute this initiative are listed below, in approximate order of importance.

1. Take overt, public action to recognize the unique importance of ocean acoustics to the Navy and the contributions of Navy-supported acoustics to national security. Such actions could range from largely symbolic (establishing ONR chairs of ocean acoustics) to substantial (adding funding to the 6.1 Ocean Acoustics Program and/or protecting it from further reductions). Establish procedures to ensure the continuance of this special status.

2. Conduct a high-level (CNR or Deputy CNR) meeting or meetings with other Federal ocean science sponsors (NSF, NOAA, DOE) to discuss the reasons for their continued reluctance to fund nearly any ocean field experimentation involving acoustics or ocean acoustic instrumentation. Attempt to obtain a commitment to increase their support for oceanographic field work in order to maintain the US ocean experimental infrastructure.

3. Establish an ocean acoustics infrastructure project (estimated cost: $2M per year) akin to the 6.1 Oceanographic Facilities Project currently in place at ONR. (The Oceanographic Facilities Project subsidizes 80% of the cost of research vessels, leveling the playing field between those research projects that require field work and those that don't.) This similar project would acknowledge the importance of ocean acoustics to the Navy by subsidizing some of the other costs of conducting ocean acoustics field work—specialized equipment, salaries for sea-going engineers and technicians, etc. These funds could be administered as a part of the ONR 6.1 Ocean Acoustics Program, or an external mechanism could be developed to distribute them across both 6.1 and 6.2 projects on an equitable basis. (The Oceanographic Facilities money is distributed more or less on a first-come, first-served basis, which would not be workable in this case.) One possible body to assist in such decision making would be an Ocean Acoustics Scientific Advisory Panel (item 4).

   Utilize some of these funds to develop a suite of major measurement systems and operate them as national assets available to all users (as, for example, are major assets in the fields of astronomy and high-energy physics). Maximize the utilization of these measurement systems and capitalize them to provide funds for eventual replacement.

4. Establish an ONR Ocean Acoustics Scientific Advisory Panel to continuously assess the health and balance of ocean acoustics S&T work and advise ONR management of any important issues. Panel members would be drawn on a rotational basis from the community and serve to obtain a consensus from the community as a whole. Several options are available for selection, including direct appointment by the CNR and Deputy CNR. Perhaps the best option would be for the CNR to express his interest in establishing such a group and see how the community responds.

5. Take whatever actions are necessary (including the initiatives listed below) to increase the average grant size and develop more multiyear programs. The Acoustic Reverberation SRP, though larger than what is envisioned here, would serve as a good paradigm.

6. Truly integrate 6.1 and more of the 6.2 funding by placing it under common management. Give extra credit to 6.1 proposals from academic institutions that

involve NRL or a Warfare Center. Give extra credit to 6.2 proposals from NRL or a Warfare Center that include significant participation by an academic institution. (Another variation on this idea would be to actually delegate program management authority for *some* components of the 6.2 program to NRL and the Warfare Centers but *require* them to produce plans for truly integrated 6.1-6.2 and laboratory/center-academia-industry projects. Such an arrangement would require a good deal of care and extensive written guidance to ensure that the Navy laboratories/centers don't skim off all the cream, but it might produce some truly integrated projects while permitting a reduction in the staff at ONR Headquarters.) Frequently, the most effective mechanism to integrate programs and transition products or concepts is to fund the same PI with different "colors" of money.

7. Make overtures to the Navy offices (e.g., OPNAV N84 and N87) that are developing plans for higher-level R&D programs (6.4 funding and above) with major ocean acoustics components or concerns. Wherever possible, develop joint and/or integrated experimental plans focused on satisfying all related ocean acoustics R&D questions while also maximizing the utilization of expensive field platforms.

8. Designate several (four to six) academic institutions (or consortia of institutions) as Institutes of Naval Ocean Acoustics to serve as central sites through which most ocean acoustics S&T would be administered. These Institutes would be located at institutions with substantial investments in infrastructure, comprehensive curricula, and extensive experience in conducting and supporting Navy ocean acoustics research. Future investments in infrastructure and improvements in sea-going capability would be focused largely on these organizations. Smaller institutions without sea-going capability would have free access to these capabilities and would be discouraged from duplicating their infrastructure. Several other Federal research sponsors have chosen a similar mechanism to maximize the availability of expensive research facilities to as many researchers as possible. These include such disparate activities as the DOD high performance computing network, the Air Force microwave electronics R&D program, and the network of NSF-funded Science and Technology Centers. The University National Oceanographic Laboratory System (UNOLS), which schedules the US fleet of oceanographic research vessels, also operates on a similar principle.

9. Establish an ocean-acoustics-only counterpart to the ARL Project and expand it to include other universities that both conduct research and grant degrees in the field. Estimated cost: $500K per year.

10. Establish fellowship programs to maintain the supply of US nationals studying ocean/underwater acoustics. Focus all graduate education dollars on the student (not on the faculty member's project) to save overhead charges. Consider establishing separate programs for specific subdisciplines at selected schools in order to get the attention of the academic institutions and leverage their in-house assets. The emphasis should be on obtaining sea-going experience. Estimated cost: $250K per year.

11. Establish a summer internship program for US-citizen undergraduates to study for a summer at universities with graduate programs in acoustics. The modest sum of $50K would support summer internships for six students between their junior and senior years. Estimated cost: $300K per year.

12. In collaboration with the ASA, establish an annual Sponsor's Award for the best ocean acoustics research paper by a student. The award would be presented at an ASA meeting and would include transportation to the meeting, hotel expenses, and a modest amount of cash (perhaps $5,000).

13. Improve collaboration and synergy between the Navy laboratories/centers and academia by sponsoring topical workshops focused on both research opportunities and future system requirements. Then actually use the outputs of these workshops to lay out program-planning documents that ultimately would lead to funding decisions.

14. Utilize one or more of the foregoing mechanisms (Scientific Advisory Board, workshops, etc.) to involve the ocean acoustics community in developing options for the global-funding decisions (how much to the major initiatives developed by the workshops, how much to individual investigators, how much to the Ocean Acoustics Institutes, etc.). However, the final decisions would still remain with the individual ONR scientific officers.

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APPENDIX A

EXAMPLES OF INFERIOR US WAR-FIGHTING TECHNOLOGIES AT THE BEGINNING OF WORLD WAR II

(from various sources)

- The finest US fighter plane in service in 1941 was inferior to the finest operational fighter planes of Japan, Germany, and Britain (the Zero, the ME-109, and the Spitfire).
- A model of the B-17 (Flying Fortress) first used in Europe by the US was so vulnerable it was unable to sustain itself in its announced purpose (i.e., deep unaccompanied daylight bombing).
- The first US tank deployed in World War II was inferior to the operational German and Soviet counterparts because of its vulnerability and high vertical profile. It did have a highly reliable and long-lived track and suspension. The best suspension probably was on the Soviet T-34, which was marketed to Russia after development in the US during the 1930s but was not put in production by the US Army.
- The ground-mount 50-caliber machine gun and the 37-mm antitank gun fielded by the US in 1941 were useless against the operational German or Soviet tanks. The replacement for these, the 57-mm antitank gun, was a British development.
- The US light machine gun was the oldest machine gun technology deployed in Europe (including second-power countries) in WW II and had a serious deficiency in the time it took to change overheated barrels (2–3 min) compared to modern European light machine guns (10–15 s).
- Not only was the most modern of the torpedoes operational in the US Navy in 1941 inferior to the Japanese torpedo of 1941 (the Long Lance) in warhead and range, but it also had serious deficiencies in depth-keeping and in operation of its magnetic detonator system. Many of the early 1941/42 US submarine skippers had their careers ruined for "lack of aggressiveness" because they sank so few Japanese ships for the number of torpedoes expended.
- Japanese Navy optics often outperformed US surface radar in the surface ship actions between New Guinea and Guadalcanal.
- Although the US Navy and the Marine Corps were the original proponents of dive bombing, the bombing sights operational in 1941 were unheated, so the sight cooled off during higher, operational altitudes and then fogged up when the dive brought it down into warm, humid, tropical air at bomb-release altitudes.

APPENDIX B

INDIVIDUALS PARTICIPATING IN THIS STUDY

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Shira Broschat, WSU
Michael Brown, U/Miami
Michael Buckingham, SIO
Martin Buffman, NUWC
Robert Carpenter, NUWC
Stanley Chin-Bing, NRL
Ching-Sang Chiu, NPS
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Jiri Tichy, PSU
Roy Tozier, NUWC
Robert Tyce, URI
Kevin Williams, APL-UW

APPENDIX C

Acoustician Study Data Request

Note: Not all questions need be answered; respond only to those for which data are available.

A. Academic and Government Laboratories and Centers

1. Provide any data on new hires per year over the past ten years for recent graduates/post docs for jobs in ocean/underwater acoustics at your laboratory.
- Have there been any RIFs of acousticians (except for cause)?

2. Contrast the amount of effort invested on ocean acoustic field experiments (in dollars, days at sea, work-years, or any other measure) per year over the past ten years.

3. Provide any available actuarial data on the average age of your full-time ocean acoustic professional staff over the past ten years.

4. How many (or what percentage) of the members of your professional staff that are considered to be acousticians actually studied ocean acoustics as a part of their graduate education?
- What degrees (and how many of each) were actually awarded to your acousticians (e.g., EE, physicist, mathematician, oceanographer)?

5. Provide whatever data are available on the levels of funding received for ocean acoustic R&D over the past ten years.
- By sponsor and funding category (6.1, 6.2, etc.) if possible.

6. Other than from ONR, do you anticipate a significant level of funding in the future from any other sponsor for basic research in ocean acoustics?

7. Provide any comments you may have regarding the future of basic research and exploratory development in ocean acoustics in your laboratory/center.

8. (Very hard question) What are your supply-vs-demand projections for ocean acousticians ten years from now? Twenty years from now?

9. Do you have any suggestions for solving any projected shortfalls in the ability of the US to satisfy its future requirements for ocean acousticians?
- Those that can only be executed with a significant increase in research funding in the area.
- Those that can be executed with little or no additional funding in the area.

B. Academic Institutions (only)

1. Over the past ten years, what have been the enrollment and graduation rates for US citizens with degrees in applicable fields (e.g., physics, engineering, oceanography, geophysics) who specialized in ocean/underwater acoustics?

- If the data are available, please provide data for each year, sorted by degree (MS, PhD, post-doc).
- How many (or what percentage) left the field (changed their major or specialty) before completing their studies?

2. Of those receiving advanced degrees in this area, what percentage are US citizens compared to ten years ago?

- What other countries are represented among those studying ocean acoustics?

3. Provide any data available on the number (or percentage) per year of US citizens receiving an advanced degree in some area of ocean acoustics who went to work in the area.

- Teaching.
- Academic researcher.
- Government lab.
- Industry.
- Government program manager.

4. Over the past ten years, have there been any changes in the size of the faculty devoted to ocean acoustics or the organizational importance of the acoustics group within the academic department?

- Are any such changes unique to ocean acoustics, or part of a series of more profound changes (e.g., decline in enrollment in all physical sciences)?

5. Would it be possible to interview a few typical students studying acoustics without faculty present? (Questions posed will focus on reasons for choosing the area, expectations for the future, etc.)

6. Provide any comments you may have regarding the future of ocean acoustics as an academic pursuit in your institution.

APPENDIX D

SELECTED QUOTATIONS AND OBSERVATIONS

This study involved a large number of personal interviews and also solicited written comments from a variety of members of the ocean acoustics community. Many of the comments, data, and observations that were provided to the author did not fit easily into the themes in the body of this report, yet nevertheless had value in describing the health of ocean acoustics research and education in the US in 1997. This appendix includes a number of observations selected from the many submitted by those interviewed for this report. Items in quotation marks are either direct quotes from written responses to the study data call or statements made to the author during interviews. In the latter case, they may differ somewhat from the exact language (but not the meaning) of the statements made during the interviews. Items without quotation marks are the author's paraphrase of information provided during visits to institutions.

- At SIO, the number of applicants in ocean acoustics is down, and the overall quality of the applicants is down somewhat, too. The Applied Ocean Science curriculum used to get seven or eight new students each year. In September 1997, it will get three.
- The size of the staff of the WHOI Ocean Acoustics Lab has declined from 15 in 1987 to 9 in 1997.
- "In low frequency acoustics, ARL:UT has produced only a single Ph.D. student in 5 years."
- "Out of about 730 applicants to UW for the EE graduate program, only 90 were US citizens; 267 were from the PRC."
- The cost to maintain a graduate student at SIO is $33K a year; but for a postdoc, it's $70K (must charge overhead on postdoc stipends).
- "We must ensure that moneys are set aside for beginning investigators. It does not need to be huge sums, but there has to be something for new start-ups."
- "The fee collected by ARL/PSU on the Naval Sea Systems Command (NAVSEA) contract used to support about 60 graduate students a year; now it's down to 25–30. ONR programs have received a significant educational subsidy from the NAVSEA contract over the years."
- Biology and computer science are growing rapidly at MIT; since the faculty size is a zero-sum game, the growth comes from areas that are not attracting enough students. Acoustics is one of those areas.
- "In the academic departments of The University of Texas at Austin, two faculty members who devoted much of their teaching and research activity to acoustics are retiring, and are not likely to be replaced with faculty with similar research interests."

- "We should encourage senior investigators to co-author proposals with junior investigators. Encouragement should be in the form of incentives—e.g., a special program."
- Twenty years ago, URI had 90 graduate students in ocean engineering, of whom 50 were in acoustics. Today URI has 18 graduate students in ocean engineering, about 12 of whom are in acoustics. The enrollment used to be 80% US citizens, while it is now 50% US.
- "In the past, research programs have supported both the faculty and students and provided the opportunity and infrastructure to produce quality, original research at the forefront of the field. However, at the present time, ONR 6.1 support for acoustics research has decreased to half of that of five years ago. The decrease in research support has had a devastating effect on the academic program. The present level of funding is just adequate to cover faculty salaries without support for (1) students salaries, (2) computer maintenance and (3) experimental infrastructure."
- "Twenty years ago, the WHOI Ocean Acoustics Laboratory would typically have one 3–4 week cruise a year. Now the field work in ocean acoustics is much more sporadic and splintered among the various scientists in the Lab. Cruises now occur infrequently, perhaps once every 2–3 years, with durations of less than 14 days. This state of affairs seriously impedes the progress of basic research in ocean acoustics and the education of the next generation of ocean acousticians."
- "In general, the cost of doing field experiments continues to rise while the funding base declines. Certainly since FY 93 NRL is conducting fewer experiments per year than in the past. Platform costs are a major driver. ONR (and NRL) have a platform support cost-sharing program, limited to 6.1 field research. It would be desirable to extend the availability of these funds to 6.2 field research as well."
- "A big difference in project support that I have noticed over the past decade is the fact that an individual's research program can no longer be supported by a single grant. In the past, a principal investigator could support themselves, a student, technical staff members and purchases of equipment—all on one grant. Now, the funding conditions require roughly four grants to do the same thing. We now typically have a small grant that will support a principal investigator for several months with some money left over for support of other activities. In order to support the rest of the program, there are student grants, equipment purchase grants, and initiative-based grants that help support field efforts. As a result, we spend much more of our time writing proposals and writing reports. This new climate is more task-oriented than program-oriented with shorter fuses on getting results. This task-oriented atmosphere involves many interruptions and is less conducive to long-term thinking about hard problems."
- "We have a problem attracting strong, new graduate students into ocean acoustics research, and this problem is getting worse with time. There are at least two major reasons for this problem. The first is the perception of students that the field is mori-

bund. The second is the inability of researchers to assure students that this is not the case. In fact, many researchers agree with them. Currently morale is very low among researchers, and many are faced with a moral dilemma: whether to make a concerted effort to recruit students when the outlook for job opportunities is so bleak or whether to stop training graduate students, one of the fundamental responsibilities of faculty at a research university."

- "In 1987, NAVOCEANO hired approximately 6 persons per year for acoustic surveying or modeling. We have recently hired about 2 persons per year with backgrounds related to acoustics."
- "The number of new Ph.Ds with ocean acoustics sea-going experience is borderline low. Most of the new hires that have done ocean acoustics thesis research or post-doctoral work are theoreticians or laboratory experimentalists."
- "In the near term we need to make sure that there is a critical mass of people who understand acoustics, even if it is not Navy acoustics. There appears to be growing commercial/medical/research work in high frequency acoustics for imaging. In addition, commercial applications of high frequency underwater acoustics should have some support for locating objects and navigating in the ocean. There is also an invigorated research and development community involved in the use of underwater acoustics and geophysics as they relate to oil exploration (their security is often tighter than ours). ONR and other Navy organizations could support generic acoustics research which contains topics in underwater acoustics as a subset. If we grow more acousticians, we will have a pool of trained people to draw on when we (or our contractors) need to hire."
- "The NPS (especially the Oceanography Department) consistently graduates several students specializing in ocean acoustics per year. The trouble is that most of those students do not practice ocean acoustics after graduation. If the Navy can make an effort to keep them doing ocean acoustics, the pipeline may not be as bad."
- "ONR should review its support of non-US citizens on academic grants. Perhaps these funds are better spent for the higher-cost experimental programs or for a post-doctoral program specifically for ocean acousticians at Navy laboratories/centers."
- "Another problem is that underwater acoustics has been and is perceived as a Navy-only research area and thus other organizations avoid funding it. The Navy could approach dual-use research funding with other Government organizations or even with foreign governments (e.g., the UK). By establishing "acoustic" centers of excellence, we may be able to increase the number of people who understand underwater acoustics as opposed to increasing the number of people who have a degree in underwater acoustics."
- "We should encourage diversity. The demographics of the US are changing rapidly, and we must take advantage of our entire resource base. We must be pro-active in recruiting non-traditional students in the field of ocean acoustics."

- "We should start collecting data to monitor the health of our field. One way is by getting statistics from JASA on the ages of people authoring papers in ocean acoustics. This will give us important feedback on what is happening over time."
- "With the shift in sponsorship of our program to the Systems Commands, the nature of ARL:UT's work has changed in several ways. First, it is much more applied in nature. Second, it is more heavily oriented toward signal processing than ocean acoustics. Third, our work is more heavily system-specific and classified, leading to a loss in opportunities to publish in the open literature. We do continue to maintain a good publishing record, however, and we do take advantage of *JUA*."
- "ONR must develop a strategic plan for the future in ocean acoustics at whatever funding levels DOD budgets allow. NRL and the academic community have a vital stake in this and must participate in this strategic planning. Only within the context of a strategic plan can we determine how to best preserve the education of ocean acousticians in our universities."
- "Generally students receive a small salary to cover living expenses and UM provides tuition remission. At the last ONR site review, all of our requests for student support were declined. Also, none of our AASERT proposals were funded this year. As a result, only a very few older students remain in the academic program and in two years the pipeline will be empty."
- "A related problem is the lack of investment in field instrumentation. NRL's equipment inventory is aging and not being re-capitalized at previous rates in this declining budget environment. The academic communities' equipment resources are similarly eroding. It may be appropriate for ONR to establish a pool of experimental equipment as a community resource to reverse these trends without requiring significant investments at a number of institutions. This will require academic and government laboratories' cooperation and planning. This would be analogous to the high performance computing resources available to a broad segment of the ocean acoustics modeling and simulation research."
- "Perception is extremely important in dealing with this problem. We must change the perception held by both potential students and principal investigators that ocean acoustics is moribund. The single most important step that needs to be taken is to stop cutting the levels of funding to ocean acoustics. Everyone expected funding cuts and some of us even thought it was a good idea, but we also expected to reach some steady-state level eventually. However, each time we thought we had reached this point to date, funding was reduced even further. This is extremely demoralizing, and it makes it difficult to plan as well. We really need some stability."
- "The deleterious effects of this problem are not apparent now, but over time they will become so. A constant influx of new talent is important in any effort. Beginning researchers bring enthusiasm and state-of-the-art skills to their employment and help to

keep the research environment vital. At the same time, the senior researchers pass along a vast amount of knowledge that they have gained over the years. There is no substitute for this knowledge, and it cannot be gained overnight. Therefore, we cannot wait until all the senior researchers of today have retired and then hire replacements tomorrow (assuming we can find them). We must ensure that we have a steady input of new researchers. If we do not, our research environment will be negatively impacted in the near future."

- "The Navy Postgraduate School has had a great difficulty in filling up the billets in its acoustics curriculum, yet the Navy labs annually educate a number of engineers and scientists in acoustics. Why doesn't the Navy direct civilian students to the PG School and better establish it as a center of educational excellence? Senior Navy scientists could be brought in to serve as visiting lecturers or to sit on thesis committees. Civilian students could take basic courses at local colleges and attend NPGS for a year to finish their degrees. NPGS also provides the opportunity to conduct classified research. While these ideas will not give us more acousticians it could strengthen the Navy base in acoustics and serve to tie the community more closely together (particularly if other organizations, e.g., Scripps, WHOI, etc., were brought into a consortium)."

APPENDIX E

ACRONYMS AND ABBREVIATIONS

AASERT	Augmentation Awards for Science and Engineering Research Training
APL-UW	Applied Physics Laboratory - University of Washington
ARL-PSU	Applied Research Laboratory - Pennsylvania State University
ARL:UT	Applied Research Laboratories: University of Texas
ASA	Acoustical Society of America
ASW	Anti-Submarine Warfare
ATD	Advanced Technology Demonstration
ATOC	Acoustic Thermometry for Ocean Climate
CNR	Chief of Naval Research
CPI	Consumer Price Index
CRP	Contract Research Program
CORE	Consortium for Oceanographic Research and Education
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DON	Department of the Navy
DURIP	Defense University Research Instrumentation Program
FY	Fiscal Year
JASA	*Journal of the Acoustical Society of America*
JUA	*Journal of Underwater Acoustics*
MIT	Massachusetts Institute of Technology
MPL	Marine Physical Laboratory (of the Scripps Institution of Oceanography)
NAVOCEANO	Naval Oceanographic Office
NAVSEA	Naval Sea Systems Command
NDRC	National Defense Research Committee
NOAA	National Oceanic and Atmospheric Administration
NPS	Naval Postgraduate Office
NRL	Naval Research Laboratory
NSB	Naval Studies Board
NSF	National Science Foundation
NUWC	Naval Underwater Warfare Center
OCRD	Office of the Coordinator of Research & Development
ONR	Office of Naval Research
ONRHQ	Office of Naval Research Headquarters
OPNAV	Office of the Chief of Naval Operations
OSD	Office of the Secretary of Defense
OSRD	Office of Scientific Research and Development
OSTP	Office of Science and Technology Policy
PI	Principal Investigator

PRC	People's Republic of China
PSU	Pennsylvania State University
R&D	Research and Development
S&T	Science and Technology
SIO	Scripps Institution of Oceanography
SRP	Special Research Project
UCSC	University of California Santa Cruz
U/Miami	University of Miami
UNOLS	University National Oceanographic Laboratory System
URI	University of Rhode Island
USGS	US Geological Survey
UT	University of Texas
UW	University of Washington
WHOI	Woods Hole Oceanographic Institution
WSU	Washington State University
WW I	World War I
WW II	World War II

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Underwater acoustics remains the principal means to detect and locate submarines and other underwater objects. For this reason, the Office of Naval Research has sponsored a vigorous research program in underwater acoustics and related fields at both academic institutions and Navy in-house organizations for many years. Unfortunately, no other Federal Government funding agency sponsors research in this area, and as a result the health, strength, and growth of the field in the US depends entirely on the ONR program. Interviews of senior US acousticians and visits to a number of major institutions indicate that recent reductions in Naval research budgets have caused a significant decline in the vitality of the ocean acoustics research community in the US, especially in its capability to train graduate students in at-sea experimental techniques and maintain its sea-going infrastructure. Although a number of initiatives are identified that would improve the situation, only an increase in financial support will completely solve the problem. The current level of Federal funding is inadequate to support long-term Navy requirements for acousticians, though it may be adequate for the current environment of reduced budgets and priorities. The strength of this field, virtually the only one entrusted entirely to ONR's care, is not being sustained

14. SUBJECT TERMS
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